Volume 29 November, 1943 *Number 11*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Heavy-Duty Detergent Type Engine Oils

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

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A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by

The Texas Company, 135 East 42nd Street, New York City

Vol. XXIX | November, 1943 | No. 11

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Heavy-Duty Detergent Type Engine Oils

THE story behind the development of the present-day detergent type lubricating oil for heavy duty engines dates back to about the middle of the '30's. It was then that the Diesel engine, formerly used only as a large, low-speed engine for power plant and marine service, began to expand as a smaller sized, medium and high-speed power plant for tractors, trucks and industrial applications. With the changes and improvements in mechanical design brought about by these new engines came lubrication difficulties to be overcome by the oil refiner with the cooperation of the engine manufacturer. Chief among these difficulties was ring sticking, piston and ring scuffing, wear and bearing failures.

It may be well to state at the outset that not all of these earlier difficulties were due to unsatisfactory lubricating oil performance despite the tendency on the part of operators to blame the oil for every failure that occurred. Engine manufacturers appreciated this and their cooperation has been one of the contributing factors in the development of the superior, all-purpose, heavy-duty, detergent type oil, adopted by the Armed Forces and available commercially today.

EARLY DEVELOPMENT

One of the first of these manufacturers of modern high-speed Diesels to appreciate the part that mechanical design and operating temperatures played in these early failures involving lubrication was the Caterpillar Tractor Company. As a result of their development of a single-cylinder Diesel test engine primarily to study piston ring sticking the oil refiner was able to develop in his laboratory a heavy-duty engine oil which provided a marked improvement in the prevention of ring sticking, elimination of scuffing and reduction of engine wear. This oil, composed of a highly-refined straight mineral oil to which a chemical compound had been added, was the forerunner of today's detergent type heavy-duty oil. This chemical compound or additive employed was invariably of the "metallic soap type" to provide the necessary cleansing or detergent action to the oil to prevent ring sticking. So we had a truly detergent oil as early as 1936.

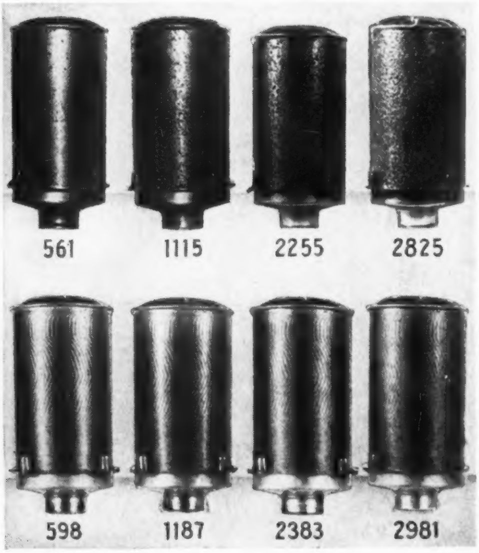
What "Detergent" Means

Before proceeding, it is well to discuss the term "detergent" and particularly its application to engine lubricating oils. The dictionary defines the action of detergency as the cleansing or purging away of foul or offending matter. This is exactly what the chemical compound added to the straight mineral base oil did in preventing the piston rings from sticking in their grooves in the Caterpillar Diesel test engine.

During the combustion of fuel in a Diesel engine, deposits are formed consisting of gummy residues and soot. In addition, decomposition of the lubricating oil reaching the rings is also influenced by this combustion process. These gummy residues act as binders for the fuel soot and build up sticky deposits on the ring lands and in the ring grooves.

The additive in the lubricating oil enables the oil reaching these engine parts to take the deposits unto itself. This is accomplished partially by dissolving them but mostly by dispersing them in a finely divided state. This washing action of the lubricating oil on these potential deposit-forming

Miles



Miles

Figure 1—Dispersion effect of lubricating oil on oil strainers—top line of strainer elements shows effect of oil of low dispersion characteristics. Bottom line shows effect of oil of high dispersion characteristics.

bodies of fuel combustion is exerted as soon as the particles reach the oil. This same action occurs in other parts of the engine reached by combustion chamber products when blow-by occurs past the piston rings. These deposit-forming materials are partly dissolved and partly dispersed in a suspended state throughout the lubricating oil and thus are able to be carried out of the engine when the oil is drained. Thus the engine is kept clean by this detergent action of the lubricating oil.

Another characteristic of detergency in engine lubricating oils is the ability to remove previously formed deposits from the surfaces of engine parts. This action is likened to that exerted by soap and water in cleansing dirty surfaces. These removed deposits are then broken up and dispersed in a finely divided state throughout the body of the oil for removal from the engine at the oil drain period.

Detergency, therefore, as related to engine oils may be defined as that characteristic which prevents the initial deposition of products of fuel combustion and oil decomposition in new or clean engines. In used engines, detergency exerts a cleansing or dissolving action on old, previously formed deposits, preventing their redeposition.

Oxidation Resistance

With the continuation of improvements in engine design permitting the development of more power for the same size and weight, new materials were necessary to withstand the higher stresses imposed. Chief among these was the copper-lead bearing which could stand heavier loads and higher temperatures than the ordinary babbitt bearing. With the rapid adoption of this bearing for heavy duty service in both gasoline and Diesel engines, it was discovered that under these more severe operating conditions ordinary motor oils were corrosive to this copper-lead mixture. This corrosiveness was brought about by the inability of this type of oil to resist oxidation, which results primarily from the action of heat and air. The resultant acidic bodies formed by this oxidation process attacked the lead in the copper-lead mixture taking it into solution and leaving a porous copper structure which crumbled and broke away. Thus it became necessary to impart oxidation-resisting properties to the oil.

Improvement in oxidation resistance of the straight mineral type engine oil, as determined by corrosiveness to the alloy type bearing, was attained by the use of chemical compounds or additives. These compounds were designated as oxidation inhibitors or corrosion inhibitors.

The corrosion inhibitors primarily afford a protection to the alloy type bearing so as to minimize the effect of acidic bodies on these bearings.

On the other hand, the oxidation inhibitors also provide a protection to this type of bearing by combatting the formation of acidic bodies; this also results in a minimizing of varnish and lacquer deposits on piston skirts.

The development of engine oils with high resistance to oxidation was furthered by the advent of the General Motors 2-cycle Diesel engine and its adoption to bus, truck and tractor service. This engine employing oil-cooled pistons and copper-lead bearings required an oxidation-resistant oil to prevent the formation of deposits and to protect the bearings against corrosion.

Property of Dispersion

During this development of an oxidation-resistant oil for Diesel engine service, another valuable characteristic of heavy-duty engine oils was discovered—that of dispersion.

The action of dispersion in a lubricating oil is of a physical nature in that the products of fuel combustion, chiefly soot, along with some oil decomposition products are held in suspension. This appears to be accomplished by the dispersing of these contaminating particles in a finely divided state throughout the body of the oil. By this action agglomeration of the particles is prevented with the result that oil filters and strainers stay clean.

Although the phenomenon of detergency employs dispersion to a large extent, the two properties should be considered separately. This is readily appreciated when one considers that while all detergent oils known today have good dispersive properties, not all oils with high dispersion values display satisfactory detergency.

Dispersion, therefore, may be defined as that characteristic of an engine oil which enables finely divided, insoluble particles resulting from fuel combustion and oil decomposition to be kept in a suspended state throughout the body of the oil. In an oil of poor dispersive qualities, agglomeration or precipitation of these products occurs to form noticeable engine deposits.

This property was found to be required to prevent the clogging of the metallic ribbon-type oil strainer placed between the oil pump and oil cooler on the General Motors Diesel. When this oil strainer element clogged with fuel soot sludge, the by-pass valve opened and the oil was by-passed around the oil cooler. This condition subjected the oil to still further oxidation as a result of the higher oil temperatures achieved and under-piston deposits in addition to bearing corrosion became a problem. Base oils with inherently good dispersive properties which were further enhanced by the use of oxidation-inhibiting additives of high dispersive characteristics eliminated this condition by keeping blow-by products of fuel combustion in a finely divided state throughout the body of the oil. This provided an oil with good oxidation resistance and satisfactory dispersion but little or no detergency. Figure 1 shows the comparative effect of oils of high and low dispersion on the cleanliness of the oil strainer element used in the General Motors Diesel engine.

It was soon found, however, that this engine along with other makes of high-speed Diesels required detergency in the engine oil in addition to oxidation inhibition and dispersion. Along about this time Caterpillar changed to the use of copper-lead bearings in certain model engines and the detergent type oils not fortified against corrosion often permitted these bearings to fail. Thus it became imperative that an engine oil with properties of oxidation resistance, dispersion and detergency, should be developed.

Other well-known manufacturers of high-speed Diesel engines also recognized the need for an improved engine oil for heavy-duty service.

Overshadowing all of these demands by new and improved engines and engine materials was the never ending desire of the oil refiner to improve his products through the ceaseless efforts of the research laboratory. Improvements in petroleum refining methods provided more stable and more highly oxidation-resistant base oils. Hand-in-hand with these advancements went research on additives for blending with these improved base oils to provide the requisite properties already discussed. This culminated in the development of a superior all-purpose lubricating oil for Diesel, gasoline, butane and other types of internal combustion engines.

LABORATORY DEVELOPMENT

With this background on the reasons for the development of a heavy-duty detergent type engine oil, let us look into the modern research laboratory of the oil refiner where these oils are conceived and review some of the test procedures employed in their development.

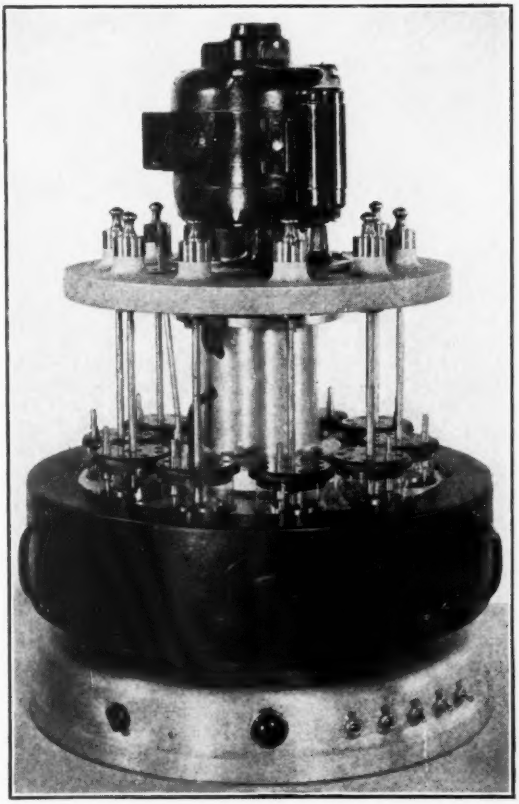


Figure 2 — MacCoull Corrosion Tester complete with ten test beakers.

The basic requirements of a heavy-duty engine oil are:

Base Oil of Desired Quality—The straight mineral oil base to which the chemical compounds are added should be selected for the type of service to which the oil is to be subjected. A moderately high viscosity index, satisfactory dispersion, and inherently good oxidation resistance are desirable characteristics. The degree of refining to which the crude is subjected determines the extent of other desirable properties such as flowability at low temperatures or pour point, low carbon forming qualities, and minimum mineral matter content.

Suitable oil additive—The chemical compounds added to the base oil must be soluble in the oil as a primary requirement. These additives are chosen depending on the function which they are to impart to the base oil. Some of the more commonly known types of chemical compounds employed as oil additives together with their functions and mechanism of action are shown in Table 1.

TABLE 1

COMMONLY USED ADDITIVES FOR HEAVY-DUTY ENGINE OILS

Purpose	*Type of Compounds Used*	*Reason for Use*	*Mechanism of Action*
Oxidation Inhibitors	Phosphorus, sulfur and nitrogen	To prevent bearing corrosion, varnish and sludging.	Reduce formation of acidic corrosive products. Form protective film on catalytic surfaces.
Corrosion Preventives (Alloy Bearings)	Phosphorus, sulfur and nitrogen	To prevent bearing failure by corrosive action.	Formation of protective film on bearing surfaces.
Detergents	Metallo-organic compounds.	To keep engine surfaces clean and prevent deposits of sludge of all types.	May be chemical reaction of detergent and varnish or physical process of solution.
Dispersants	Metallo-organic compounds.	To keep potential sludge deposits in suspension to prevent their depositing out in engine.	Peptize sludge particles and prevent coagulation.
Extreme Pressure Improvers (Break-in properties)	Halogen, sulfur, nitrogen and phosphorus.	To reduce engine wear and prevent scuffing.	Formation of lubricating film to prevent seizure when oil is forced out.
Rust Preventives	Amines and fatty acids.	To prevent rust in new engines during storage or shipment.	Preferential wetting of surface by oil.

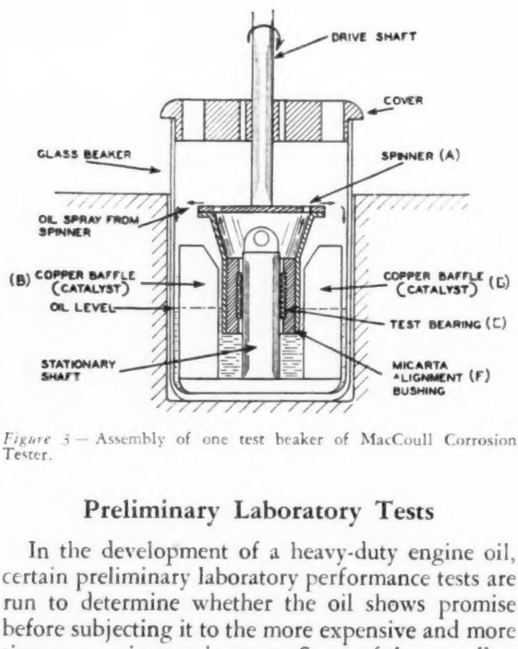


Figure 3 — Assembly of one test beaker of MacCoull Corrosion Tester.

Preliminary Laboratory Tests

In the development of a heavy-duty engine oil, certain preliminary laboratory performance tests are run to determine whether the oil shows promise before subjecting it to the more expensive and more time-consuming engine tests. Some of these preliminary tests are well known and universally used while others have been devised by each oil refiner's laboratory and their use thereby confined to that laboratory. It may be of interest to discuss briefly some of these preliminary tests as follows:

Bearing Corrosion *by MacCoull Test**

This test has been developed to determine the stability of engine oils at high temperatures as indicated by their tendency to corrode bearing metals. The apparatus for this test has been constructed so as to reproduce as closely as possible the conditions existing in engines: oil is circulated through a rotating bearing, sprayed through air and repassed through the bearing. The additive employed to retard oil oxidation must be active at all operating temperatures and consequently the MacCoull test is run at 250° F. and 350° F. The latter temperature is believed to be as high as that reached by the oil at the bearings in heavy-duty engine service.

Oils may also be tested with different bearing materials such as high-lead babbitt, copper-lead, cadmium-silver, hardened lead, lead-plated copper-lead, indium-coated copper-lead, and silver-plated copper-lead. In general, oils are tested with plain, uncoated copper-lead bearings since this bearing is being more widely used and is most subject to oil corrosion.

During this test weight losses of the bearings are determined at 2-hour intervals throughout the 10-hour total test period. Comparison of MacCoull results for an uninhibited motor oil with those for the heavy-duty detergent type oil are shown as follows for copper-lead bearings at 350° F.

*"An Oil Corrosion Tester" — MacCoull, Ryder & Scholp, SAE Transactions, August, 1942, pp. 338-345.

	Uninhibited Motor Oil	*Heavy-Duty Detergent Oil*
Bearing Weight Loss, Mgs.		
@ 2 hours	7	0
@ 4 hours	48	0
@ 6 hours	75	0
@ 8 hours	95	1
@ 10 hours	109	4

Good correlation has been found to exist between this corrosion test and laboratory engine tests at similar oil temperatures. It should be understood, however, that this corrosion test does not eliminate the necessity for full-scale engine tests since there are other factors in engine operation, both gasoline and Diesel, which affect the corrosion of copper-lead bearings.

Dispersion Test

The purpose of this test is to determine the ability of an oil to disperse and hold in suspension carbon black which may be considered comparable to fuel soot or blow-by carbon from the combustion chamber of an internal combustion engine.

Equal weights of the test oil and kerosine are mixed together with one gram of carbon black for exactly five minutes. This mixture is then centrifuged for exactly five minutes and 1/3 of the centrifuge tube contents poured off. From this decanted portion, an accurately measured 5 ml. quantity is removed and diluted with 55 ml. of kerosine and shaken thoroughly. The dispersion value of the test oil is then determined by visual comparison of this latter mixture, with a series of graduated standards.

These graduated standards are prepared in a manner similar to the above with the exception that different amounts of the centrifuged suspension of oil-kerosine-carbon black are used in each instance to provide varying densities of carbon black dispersion. Each standard is assigned a number which is twice the amount of oil-kerosine-carbon black used in its preparation, thus providing a series from 2 to 14 in two unit increments. The higher the number the greater the dispersion characteristics of the oil. Some idea of the relative dispersion values for various oils may be obtained from the following:

Type of Oil	*Dispersion Value*
Distilled straight mineral oil	0
Residual straight mineral oil	10
Residual straight mineral oil + oxidation inhibitor	10
Residual straight mineral oil + oxidation inhibitor + detergent	14

Referring to Figure 4, it will be observed that the oil having poor dispersive properties is almost transparent with the carbon black in a layer at the bottom of the bottle after centrifuging. The oil showing high dispersive properties is almost opaque

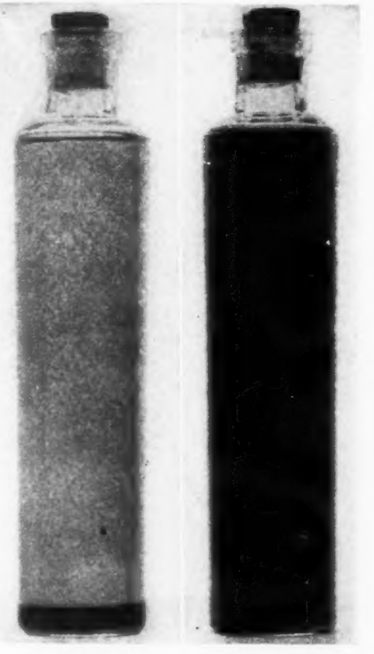


Figure 4—Comparison of oils of low and high dispersion by laboratory dispersion test. Bottle on left shows oil of low dispersion, while bottle on right shows oil of high dispersion.

showing satisfactory dispersion of the carbon black after centrifuging.

Foam Test

The tendency of some heavy-duty detergent type engine oils to foam during service was not long in being discovered. This condition was observed to occur wherever the oil was agitated with excessive quantities of air such as exists at the scavenging pump in the oil system of radial aircraft engines.

Accordingly, a laboratory foam test has been developed for determining the tendency of lubricating oil foam, produced by mechanical agitation in the presence of air, to break and return to the oil phase.

This test consists of heating a quantity of the oil under test to 75° F. for SAE 10, 20 and 30 grades and 120° F. for SAE 40, 50 and 60 grades. The heated oil is then stirred for three minutes with an electrically driven household mixer equipped with round paddles and operating at 980 to 1000 rpm. Immediately following this stirring the oil is poured into a glass graduate. With the test temperature being maintained, the total volume of oil plus foam as well as the volume of clear oil is observed every 10 minutes for a period of 60 minutes. The volume of foam is determined as the difference between these readings.

Typical test results for foaming and non-foaming oils by this method are shown as follows:

Volume of Foam, cc.	*Foaming Oil*	*Non-foaming Oil*
@ 0 mins.	350	340
@ 10 mins.	345	190
@ 20 mins.	340	45
@ 30 mins.	330	15
@ 40 mins.	320	0
@ 50 mins.	310	
@ 60 mins.	300	

The actual appearance of foaming and non-foaming oils in their graduates after standing a short while following stirring is shown in Figure 5. Note that the oil with poor foam breaking characteristics has a volume of oil plus foam of about 400 cc with a clear oil layer of only 50 cc. This is compared with an oil whose foam has completely broken except for 5 or 10 cc of foam after the same length of time.

It should be understood that practically all oils of the same viscosity have approximately the same amount of foam at 0 minutes or immediately after stirring. It is the rapidity with which the foam breaks that determines a non-foaming oil.

Almen Test

This test is a laboratory procedure used to compare and evaluate the "film strength" or extreme pressure characteristics of fluid lubricants.

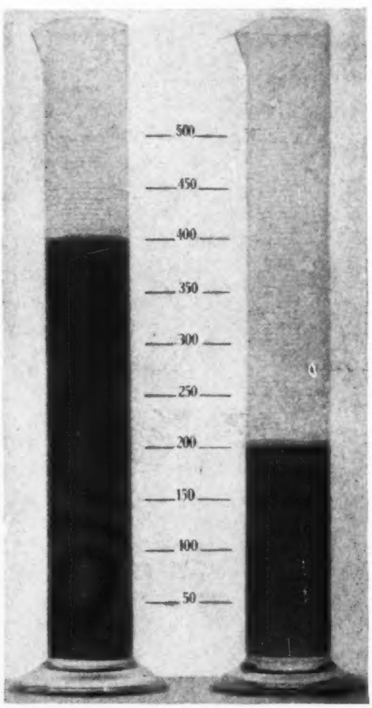


Figure 5—Comparison of foaming and non-foaming oils—graduate at left shows oil of poor foam characteristics, while graduate at right shows oil of satisfactory foam characteristics.

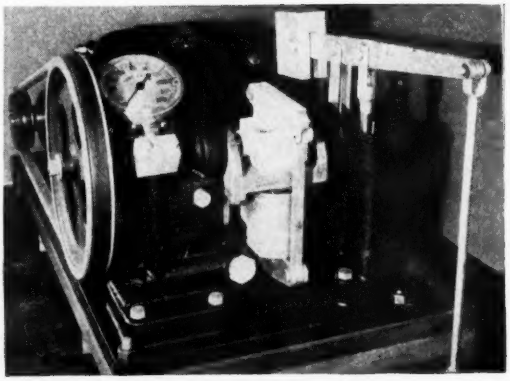


Figure 6—Almen Test Machine for determining "film strength" or extreme pressure characteristics of fluid lubricants.

The Almen Test Machine shown in Figure 6 as used for this purpose provides for the application of steadily increasing load to the top half of a soft steel bushing in which a soft steel shaft rotates at a speed of 600 rpm. The bushing is submerged in the oil under test. When sufficient load has been applied to rupture the oil film and cause seizure, the test shaft and two bushings are usually welded together and the driving nib sheared from the end of the shaft. The amount of load applied to cause failure is observed and reported in pounds as the Almen Test Value for that lubricant. An average of at least six determinations is used as the final value.

Typical Almen Values for oils with and without Extreme Pressure qualities are:

Ordinary motor oil (low E.P. qualities) 6 to 8 lbs.
Heavy-duty detergent type oil (high E. P. qualities) . . . . 20 to 30 lbs.
Extreme pressure gear oil . . . . 25 to 30 lbs.

Other Typical Laboratory Tests

Additional laboratory performance tests obtained on heavy-duty oils during their development include other well-known oxidation tests; thermal stability; emulsion; compatability with existing company products, competitive products and used oils; effect of water contamination; effect of various oil filters; effect of fuel dilution; storage stability; reclaiming and other tests of a miscellaneous nature.

Physical Tests

Following the successful completion of the foregoing preliminary laboratory performance tests, the physical tests on all grades, SAE 10, 20, 30, 40 and 50, of the heavy-duty detergent-type oil being developed are determined. These tests include: appearance and odor; gravity, °API; flash and fire points, ° F.; Saybolt Universal and kinematic viscosities at 100° F., 130° F. and 210° F.; viscosity index; color by Lovibond, ASTM or Tag-Robinson

methods; pour and cloud points, ° F.; copper strip corrosion at 212° F.; carbon residue; precipitation number; neutralization number; ash and additive contents.

Laboratory Engine Testing

The next step in the development of the heavy-duty engine oil is its testing in laboratory engines to confirm the promising characteristics indicated by the preliminary tests. These engine tests in which a single-cylinder Diesel and full scale gasoline and Diesel engines are used are designed to subject the oil to the severest conditions of break-in, high load and sustained high-speed high load conditions. The following engines and test procedures are those generally employed to determine the oil's ability to meet these conditions as well as to obtain the approval of engine manufacturers.

Caterpillar Engine Tests*

The Caterpillar Tractor Company "has determined that a lubricant, to be designated as a superior lubricant for 'Caterpillar' Diesel engines, must possess all of the following qualifications as determined by full scale engine operating tests. It should:

A. prevent ring sticking.

B. form a minimum of deposits on the liner, piston and rings.

C. be non-corrosive to bearings, filters and other engine parts.

D. show high resistance to scratching of rings and liners.

E. show low cylinder liner and ring wear.

F. insure open oil channels and free acting oil controls."

In order to determine the ability of an engine lubricating oil to meet qualifications A, B, D, E & F

*"Diesel Lubricant Test Manual," Caterpillar Tractor Co., Research Department, February, 1943.

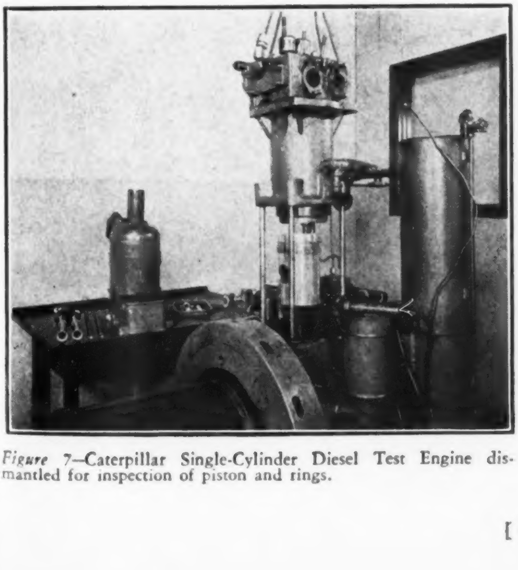


Figure 7—Caterpillar Single-Cylinder Diesel Test Engine dismantled for inspection of piston and rings.

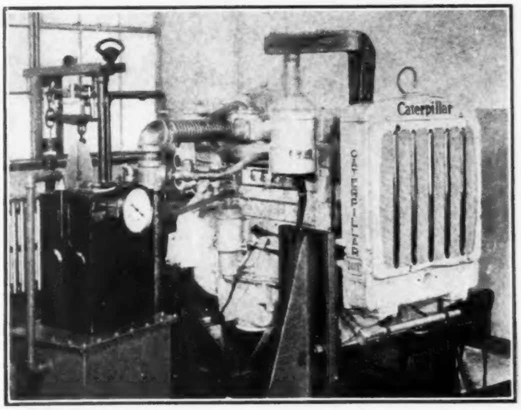


Figure 8—Specially equipped 4-cylinder Caterpillar Diesel Test Engine.

Caterpillar has developed a special type of single cylinder Diesel test engine (5¾" x 8") which has been made available to the Oil Industry for laboratory use. This engine which can be dismantled quickly for inspection of the cylinder liner, piston and rings is shown in Figure 7.

A specially equipped four-cylinder Caterpillar Diesel test engine (4¼" x 5½") is used for determining the ability of the oil to meet qualification C as well as to provide additional data on the other characteristics desired. This engine is shown in Figure 8.

A brief discussion of each of the three classes of laboratory engine test methods developed by Caterpillar may be of interest.

Test No. 1-A (480 Hour Endurance Test)

The object of this test is "to determine the effect of the lubricant on ring sticking, wear and accumulation of deposits during a 480 hour endurance test."

The single-cylinder test engine is equipped with an oil-cooled piston assembly and a water-cooled oil cooler for controlling oil temperature. A new cast-iron cylinder liner, new aluminum piston and new piston rings are installed for each test. Measurements of piston, rings and liner are made before the start of the test so as to determine the wear at the test termination.

At the start of each test the engine is given a break-in run under gradually increasing speeds and loads for a six-hour period. The crankcase oil is then drained, fresh oil installed and the endurance test conducted in accordance with the following conditions:

Length of Test	480 hours
Engine Speed	1000 R.P.M.
Load	19.8 BHP (75 lbs./sq. in. BMEP)
Cooling Water Temperature	175° to 180° F

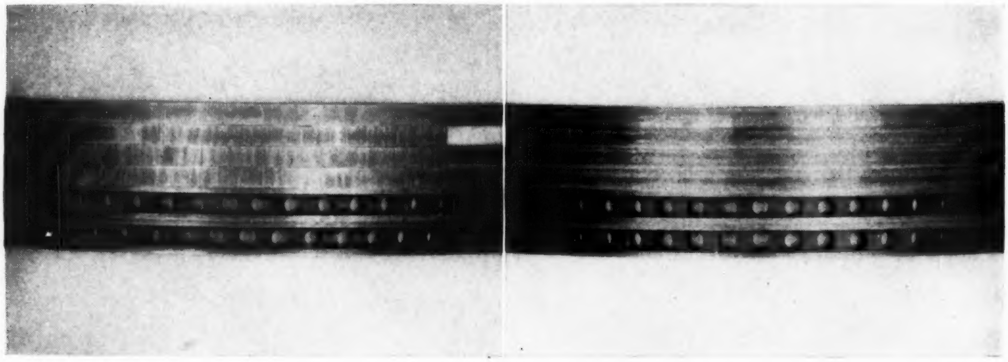


Figure 9—Comparison of piston rings from Caterpillar "Scratch Test" showing performance of oil of poor load-carrying capacity at left, with oil of satisfactory load-carrying capacity at right.

Temperature of Oil to Bearings	145° to 150° F
Exhaust Back Pressure	1" mercury, max.
Oil Change Periods	120 hours

Test No. 2 (Accelerated Run-In and High Load Test)

The object of this test, commonly known as the "Scratch Test," is "to check the qualities of the lubricating oil under conditions of accelerated run-in and high load which indicate the load carrying capacity of the oil film." It is known that by improving the extreme pressure characteristics of an oil, metal-to-metal contact and possible welding is prevented and engine wear greatly reduced thereby. This property is particularly desirable during break-in running of engines and sudden high load applications.

The same single-cylinder Diesel test engine is employed without the oil-cooled piston and with a pack type oil filter replacing the oil cooler and metal edge type oil strainer used in Test No. 1A. A special cylinder head and a different type of piston are also employed in this test.

This test is composed of two runs of 3⅓ hours duration. A new cylinder liner and piston and ring assembly is used for each run. SAE 10, 20 and 30 grades of lubricating oil are tested by this method requiring the completion of each run without scratching of liner or rings in order to pass satisfactorily.

Engine operating conditions maintained during each run are briefly:

Oil Grade Tested	*SAE 10*	*SAE 20 and 30*
Load for 10 mins.	Idle	Idle
Load for 10 mins.	7.0 BHP @ 500 R.P.M.	
Load for 3 hours @ 900 R.P.M.	Determined by calculated fuel rate	
Water Temperature	140± 5° F	175± 5° F
Inlet air temperature	90± 2° F	90± 2° F
Oil pressure	30 lbs./sq. in.	30 lbs./sq. in.
Oil temperature	140± 5° F	140± 5° F

The appearance of rings after operation with an oil of poor load carrying capacity is compared with those for an oil of satisfactory load carrying capacity as shown in Figure 9.

Test No. 3-A (120 Hour Oil Stability and Bearing Corrosion Test)

The object of this test, commonly known as the Caterpillar D-4400 Test, is "to check the stability and bearing corrosion characteristics of the lubricating oil."

The engine used in this test is a specially equipped four-cylinder (4¼" x 5½") Caterpillar Diesel test engine with a metal edge type oil strainer but no oil cooler. The engine is operated either in a hot box or equipped with a shroud around the radiator fan to provide the requisite high intake air temperatures and jacket water temperatures for this test.

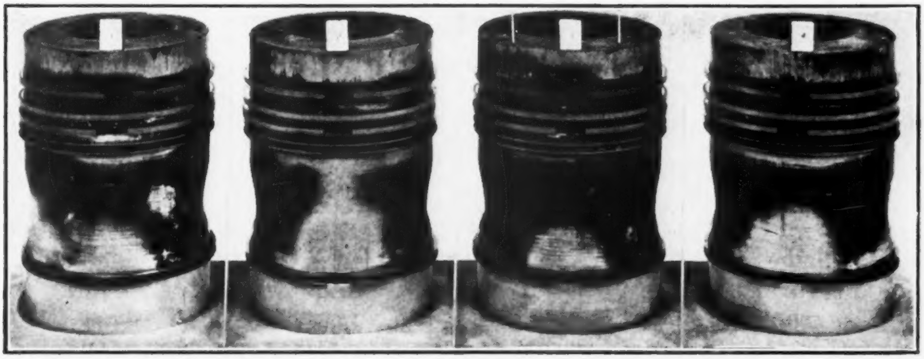
For each test the engine is fitted with at least two new cylinder liners, two new piston assemblies and two new copper-lead precision insert bearings. These bearings are weighed carefully before and after the test to determine the weight loss incurred.

Following the completion of a break-in run under varying speeds and loads, the oil is changed and the regular run conducted in accordance with the following operating conditions:

Length of Test	120 hours
Engine Speed	1400 R.P.M.
Load	37 B.H.P.
Water Outlet Temperature	200° F
Intake Air Temperature	140± 5° F
Oil-To-Bearings Temperature	212° F
Oil-To-Bearings Pressure	30 lbs./sq. in.
Oil Changes	None

Photographs of pistons after 120 hours on a poor oil are compared with the results of a similar test on a heavy-duty detergent type oil in Figure 10.

An oil which had satisfactorily passed all three engine tests and any field tests designated by Cater-



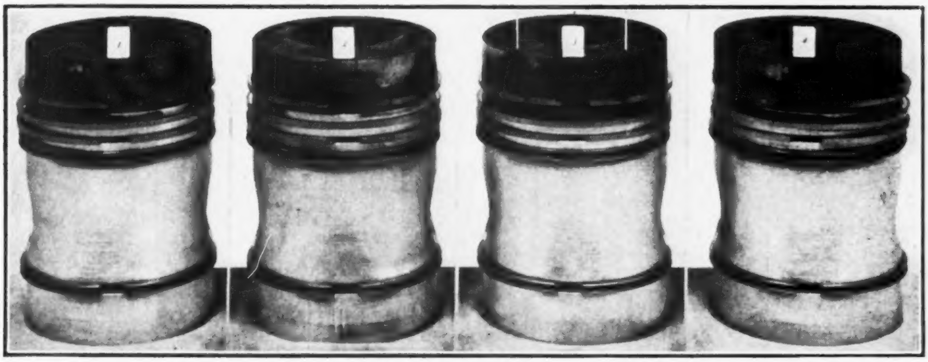


Figure 10—Comparison of pistons from Caterpillar D-4400 Test showing performance of poor oil (top) with a satisfactory heavy-duty detergent type oil (below).

pillar was given a Caterpillar Tractor Company certificate and as such was listed as a "superior, all purpose, lubricant for 'Caterpillar' Diesel engines." Although Caterpillar has recently cancelled these certificates on oils on their list, their engine tests are amongst those required for qualification of an oil against Army specifications.

General Motors Diesel 500-Hour Test

This test is employed to indicate the oxidation resistance and to some extent the detergency of a heavy-duty engine oil. Originally this test was designed as an accelerated break-down test for heavily loaded mechanical parts and its severity is considered worse than would ever be encountered in actual field service.

The test is conducted in strict accordance with General Motors 500-Hour Diesel Lubricating Oil Test procedure. An SAE 30 grade of oil is used and the length of test corresponds approximately to 30,000 road miles in service.

The engine employed in this test is a General Motors "71" series of either three, four or six cylinders. New parts installed for each test include at least one new piston, a complete set of new compression and oil control rings for all pistons and at least two new copper-lead connecting rod and crankshaft bearings which have been carefully weighed prior to their installation.

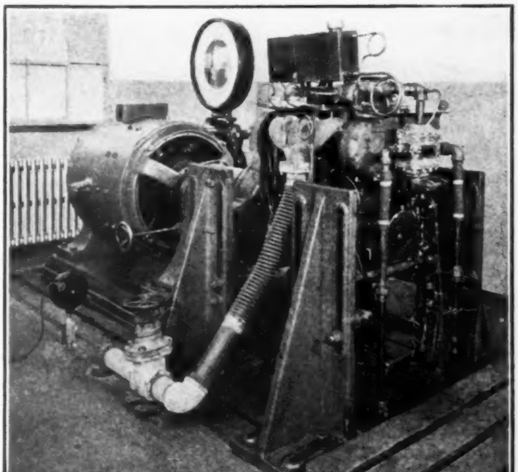


Figure 11—General Motors Model 3-71 Diesel Engine set-up for 500-hour Diesel Lubricating Oil Test.

It is of interest to note that the oil by-pass valve which permits the oil to flow around the oil strainer and oil cooler when the strainer becomes clogged is blocked during this test to insure that all the oil passes through the strainer and cooler. In addition, a large absorbent type oil filter with a by-pass is installed after the first 144 hours of the test.

The engine is broken in on the oil under test in accordance with a 16-hour break-in schedule of increasing speeds and loads. The oil is changed and following a 5-hour adjustment run under regular test operating conditions, the oil is changed again. The 500-hour endurance test is then conducted in strict accordance with the following operating conditions.

Speed, R.P.M.	2000	
Load, BHP		
3-cyl.	80 ± 2	
4-cyl.	106 ± 3	
6-cyl.	160 ± 4	
Water Out Temperature °F	180 ± 3	
Intake Air Temperature °F.	105 ± 5	
Diesel Fuel Temperature °F	120 ± 5	(at manifold)
Sump Oil Temperature °F	230 ± 1	
Exhaust Back Pressure, in. mercury	6	
Oil Consumption, lbs./hr. max.		
3-cyl.	0.20	
4-cyl.	0.27	
6-cyl.	0.40	
Oil Filter Flow Rate, gals./hr.		
3-cyl.	30	
4-cyl.	40	
6-cyl.	60	
Oil Changes	None	

The appearance of pistons and rings from this test conducted on both an ordinary motor oil and a detergent type heavy-duty oil are compared in Figure 12.

Test Requirements

1. The oil must satisfactorily lubricate all engine parts.
2. No bearing corrosion, underpiston deposits, ring-sticking, ring scuffing or scoring, excessive piston skirt deposits, ring land and groove deposits, oil strainer clogging, excessive oil filter deposits, foaming, excessive air intake port deposits, etc. shall be experienced.
3. No appreciable precipitation should occur when heating a mixture of one part of used test oil with four parts of new oil at 300° F. for 120 hours. This test indicates the ability of the oil to retain soluble oxidation products in solution instead of precipitating them to form sludge when fresh oil is added as make-up or at oil changes.

General Motors states that "lubricating oils fulfilling these requirements are considered satisfactory for use in series '71' engines for heavy-duty service, and recommended for further field testing."

Chevrolet 36-Hour Engine Test

This gasoline engine test is listed by the Coordinating Research Council as CRC Designation L-4-243 entitled "CLR Procedure for 36-Hour Engine Test for Oxidation Characteristics of Heavy-Duty Crankcase Oil." As such it is being widely used at the present time as one of the requisite laboratory engine tests for the approval of all-purpose engine lubricating oils by the U. S. Army against their specification 2-104B.

According to CRC Designation L-4-243, "this method is intended for use in determining the oxidation and bearing-corrosion characteristics of engine crankcase oils designed for use under heavy-duty service conditions." It is not intended as a test to evaluate the detergent characteristic of a heavy-duty engine oil and its relationship to ring sticking. This test is conducted on SAE 10, 30 and 50 oils with a lower oil temperature being employed for the SAE 10 grade.

The engine used for this test is a conventional Chevrolet engine with 216.5 cu. in. piston displacement and 6.5 to 1 compression ratio. A complete set of new piston rings and two carefully weighed copper-lead connecting rod bearings are installed for each test run. Following a prescribed run-in schedule of increasing speeds and loads the engine is operated on a fresh charge of the test oil under the following standard conditions:

Engine Speed, R.P.M.	3150 ± 25
Load, BHP	30 ± 1
Total Operating Time, hrs.	36
Spark Advance, degrees BTC	52 ± 5
Coolant Outlet Temperature °F	200 ± 2
Coolant Inlet Temperature °F	190 min.
Crankcase-Oil Sump Temperature °F	
SAE 30 grade	280 ± 2
SAE 10 grade	265 ± 2
Air-Fuel Ratio	14.5 ± 0.5 to 1
Exhaust Back Pressure, in. of mercury	1.0 ± 0.5

At the conclusion of the test, the engine parts are

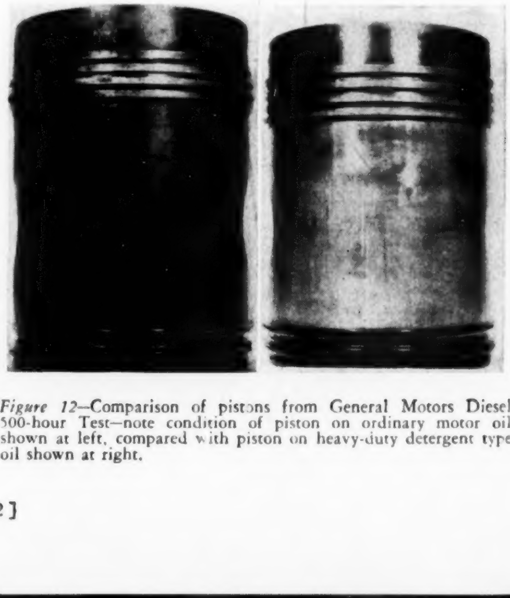


Figure 12—Comparison of pistons from General Motors Diesel 500-hour Test—note condition of piston on ordinary motor oil shown at left, compared with piston on heavy-duty detergent type oil shown at right.

inspected and their condition with respect to varnish and sludge deposits is rated on a scale from 10 to 0. The rating of 10 is given to parts showing no deposits. Lower ratings indicate increasing amounts of deposit with 0 as the maximum or worst condition. A comparison of the varnish deposit ratings and sludge deposit ratings for an ordinary motor oil with poor oxidation resistance and a heavy-duty detergent oil with good oxidation resistance is shown in Table 2. Included in this table are weight losses of the copper-lead bearings used in the testing of each of these oils.

TABLE 2
Chevrolet 36-Hour Engine Test Results
SAE 30 Grade

	Ordinary Motor Oil	*Heavy Duty Detergent Oil*
Varnish Deposit Ratings		
Piston skirts	9	10
Rocker-arm cover plate	7	10
Push-rod cover plate	7	10
Cylinder walls	10	10
Crankcase oil pan	8	10
Varnish total	41	50
Sludge Deposit Ratings		
Rocker-arm assembly	8	9
Rocker-arm cover plate	8	9
Push-rod cover plate	8	9
Oil screen	7	10
Crankcase oil pan	9	10
Sludge total	40	47
Combined engine deposit rating for varnish and sludge	81	97
Copper-Lead Bearings		
Total weight loss of both bearings, gms.	2.36	0.04

FIELD TESTS

The well known axiom "the proof of the pudding is in the eating" applies only too well to the lubricating oils developed today in the oil refiner's modern research laboratory. Regardless of how satisfactorily the oil performed in the laboratory or how closely the engine tests simulated actual field operating conditions, the true ability of the product is determined from its performance in the equipment of the everyday user.

Although laboratory engine tests are rightfully designed to subject the oil under test to the extremes of service severity on the premise that if it stands up under that it will stand up under anything, there are conditions of abnormal or subnormal service which make heavy demands on the oil and which are not duplicable in the laboratory. It is primarily these operating conditions under which the oil refiner prefers to see his lubricant field tested.

Field tests of newly developed engine lubricating oils are usually conducted in gasoline and Diesel engines operating in widely varying services including bus, truck, tractor, marine, stationary, and railroad.

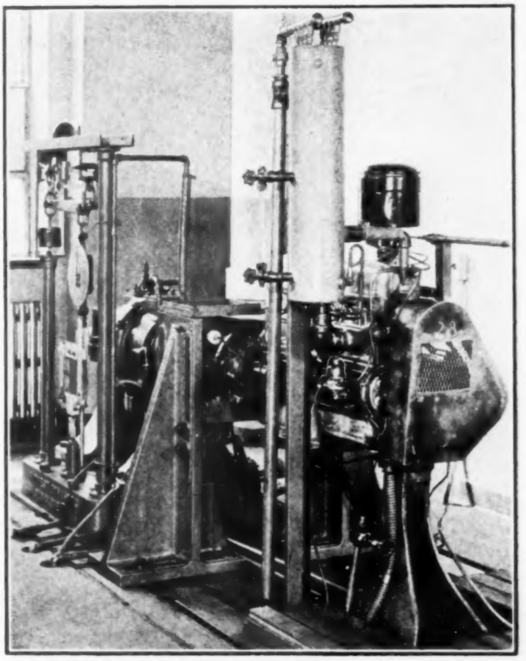


Figure 13—Chevrolet Engine set-up for conducting 36-hour engine test to determine oxidation characteristics of heavy duty engine oils.

It may be of interest to discuss briefly the results of typical field tests of a typical heavy-duty detergent oil in bus service and in tractor service.

Bus Service

Five additive type oils of SAE 30 grade were tested in ten General Motors Model 6-71 Diesel-powered buses for a total of 580,000 miles. In order to provide check determinations, each oil was tested in two buses.

The oils tested consisted of both the heavy-duty detergent type and the ordinary oxidation-inhibited non-detergent type. The results of these tests are

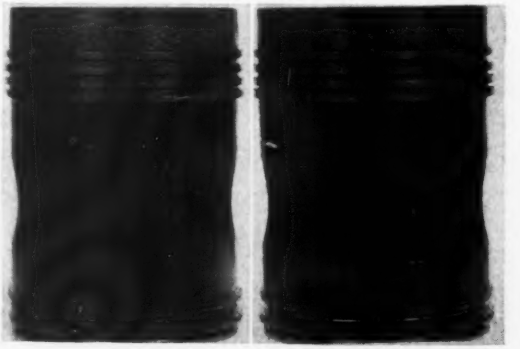


Figure 14—Comparison of pistons after field tests in General Motors Diesel bus engines. Piston at left ran on ordinary oxidation-inhibited motor oil for 59,000 miles. Note deposits on ring lands, piston skirt, and in oil control rings and grooves. Satisfactory appearance of piston at right obtained with heavy-duty detergent type oil after 65,000 miles.

shown in tabular form in Table 3 wherein a non-detergent type engine oil is compared with detergent type oil. In addition, the condition of representative pistons after operation on each of the two oil types is compared in Figure 14.

It is observed that the heavy-duty detergent type oil provided the more satisfactory performance.

TABLE 3

Comparison of Non-Detergent and Detergent Type Oil Performance in Diesel Bus Engines

Oil Type	*Oxidation—Inhibited Non-Detergent*	*Oxidation—Inhibited and Detergent*
Bearing Corrosion	None	None
No. Rings Stuck per Engine	9	2
Oil Ring Deposits (% Clogged)	60	0
Air Port Deposits (% Clogged)	15	15
Ring Wear, grams/cylinder	3.92	2.41
Piston Skirt Deposits	Moderate	Moderate
Ring Groove Deposits	Normal	Normal
Deposit Above Top Ring	Moderate	Moderate
Purolator Deposits	Light	Trace
AC Filter Deposits	Heavy	Clean to Light
Used Oil Analyses	No appreciable oxidation.	

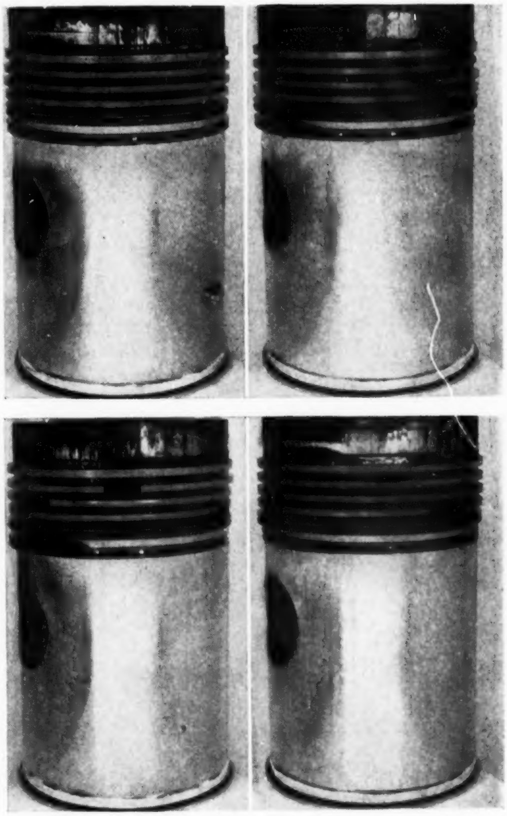


Figure 15—Appearance of pistons from 4-cylinder Diesel tractor engine after 2759 hours on a heavy-duty detergent type oil in tractor field service.

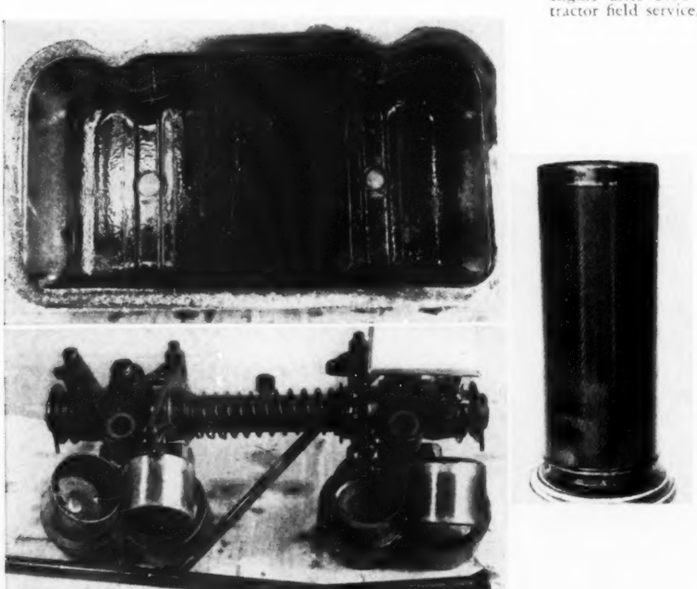


Figure 16—Sludge-free condition of crank pan, rocker arm and oil strainer element from 4-cylinder Diesel tractor engine after 2759 hours on a heavy-duty detergent type oil in tractor field service.

Tractor Service

Field tests of a heavy-duty detergent oil in several Diesel engines in tractor service have provided some interesting results after more than 12,000 hours of operation.

Photographs of the pistons removed from a four-cylinder Diesel after 2759 hours are shown in Figure 15. Note the cleanliness and freedom from ring sticking of these pistons after this extensive service. The clean condition of strainers, rocker arms and crankpan shown in Figure 16 also reflect the detergent and dispersive ability of this oil. Satisfactory protection of the copper-lead bearings by this same oil after 1040 hours in another Diesel engine is indicated by Figure 17.

Detergent Oils Adopted by Army

The U. S. Army's admirable standardization program initiated at our entrance into World War II required that for simplification of the supply problem an engine lubricating oil be found which could be used universally. That is to say an oil for the Army Ground Forces which would be suitable for all types of engines, with all types of engine bearing materials and for all types of service.

Considerable data was already available on the satisfactory performance of heavy-duty engine oils in the various types of automotive engines in civilian vehicle service. It was this heavy-duty detergent type engine oil which was finally adopted by the Army as the oil to provide the desired universal applicability.

U. S. Army Specification 2-104B covering this all-purpose engine lubricating oil was drawn up around the very laboratory engine tests by means of which this product was developed by the oil refiner. The requirements of this specification shown in Table 4 are of interest.

Mr. G. A. Round, Consultant on Fuels and Lubricants to the Ordnance Department, states: "To date the results with heavy-duty oils have been quite satisfactory and comparable with those obtained in civilian service. Engines have been notably cleaner, ring and valve gumming are not reported, bearing corrosion troubles have disappeared and, when the stipulated procedure was followed, there was no difficulty in changing from ordinary to heavy-duty oils . . . it is difficult to visualize trying to find anything better to satisfy all the needs of the Army Ground Force Units than the modern 'Heavy Duty Oils,' or as the Army terms them, 'All-Purpose Engine Oils'."

TABLE 4

Oil, Engine, for Use in Automotive Gasoline and Diesel Engines

U. S. Army Specification No. 2-104B (Condensed)

D. General Requirements

D-1. Engine oil shall be non-corrosive to bearings and engine parts, shall not cause or permit piston ring sticking or clogging of oil channels and shall minimize cylinder and ring wear. This engine oil shall provide satisfactory lubrication of high speed, automotive type gasoline, Diesel, or spark ignition fuel engines when operated under all conditions of service. Additive agents, if used, shall not appreciably increase the tendency of the base oil to foam.

D-2. Additive agents, if used, shall remain uniformly distributed throughout the oil at all temperatures above the pour point up to 250° F. If the oil is cooled below its pour point, it shall regain its homogeneity on standing at a temperature of not more than 10° F above the pour point of the oil.

E. Detail Requirements

E-2. Engine oils covered by this specification shall be in accordance with the following.

Test	*Test Limits*		
	Grade SAE 10	*Grade SAE 30*	*Grade SAE 50*
Viscosity, Saybolt Universal Seconds at 130° F	90 to less than 120	185 to less than 255	. . . .
Seconds at 210° F	. . . .	. . . .	95 to less than 105
Viscosity Index, minimum	85	55	75
Pour Point, °F, maximum	minus 10	0	15
Pour Point after dilution with 20 percent Precipitation Naphtha, °F, maximum	minus 40	minus 40	. . . .
Flash Point, °F, minimum	360	390	400

F. Methods of Tests

F-3. *Qualification Tests.* All engine oils procured under this specification shall be tested for qualification as follows:

Required when the finished engine oil uses an additive not previously used in an engine oil qualified by the Ordnance Department.

SAE 10 Grade

1. Chevrolet 36-hr. Oxidation Test
2. Caterpillar Test No. 1-A
3. Caterpillar Test 2-A
4. Caterpillar Test No. 3-A

SAE 30 Grade

1. G. M. Diesel 500-hr. Test
2. Chevrolet 36-hr. Oxidation Test
3. Caterpillar Test No. 1-A
4. Caterpillar Test No. 2-A
5. Caterpillar Test No. 3-A

SAE 50 Grade

1. Chevrolet 36-hr. Oxidation Test

Required when the finished engine oil uses an additive previously used in an engine oil qualified by the Ordnance Department.

SAE 10 Grade

1. Chevrolet 36-hr. Oxidation Test
2. Caterpillar Test No. 1-A
3. Caterpillar Test 2-A

SAE 30 Grade

1. Chevrolet 36-hr. Oxidation Test
2. Caterpillar Test No. 1-A
3. Caterpillar Test No. 2-A

SAE 50 Grade

1. Chevrolet 36-hr. Oxidation Test

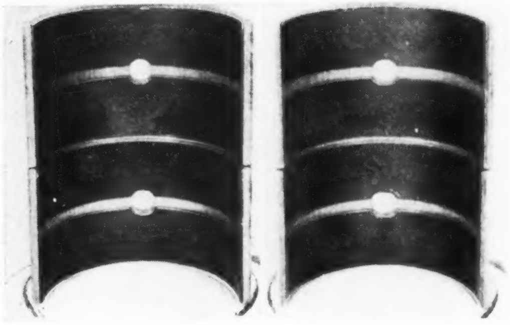


Figure 17—Satisfactory appearance of copper-lead bearings from 4-cylinder Diesel tractor engine after 1040 hours on a heavy-duty detergent type oil in tractor field service.

SERVICE CHARACTERISTICS

As a result of laboratory tests and testing under actual field service conditions, certain characteristics about the performance of heavy-duty detergent oils have been observed. These service characteristics are discussed briefly as follows:

Oil Drain Periods

The length of the oil drain period is dependent primarily on the extent to which the oil is contaminated or decomposed while in service. This depreciation results generally from two major sources: (1) External to the lubricating oil system and including products of fuel combustion, dust, road dirt and wear particles. (2) Inherent in the lubricating oil and consisting of decomposition products as a result of oxidation. Contamination, as such, depends on the engine design and mechanical condition, operating conditions of service, quantity of oil required, oil consumption, engine maintenance, size and efficiency of oil filters and type and quality of oil.

Inasmuch as a heavy-duty oil with its detergent and dispersive properties is taking up more and more of these contaminants for removal when the oil is drained, there is a decided possibility that an overloaded condition will occur. When this happens some of the finely dispersed contaminants may precipitate out of the oil causing deposits on vulnerable engine parts. Accordingly the oil drain periods for these oils should not be extended too long.

In general, the recommendations of engine manufacturers should be followed in establishing an oil drain period. Where such recommendations are not available the engine operator and oil supplier should cooperate to determine the oil drain period based on engine appearance and used oil analyses.

Breaking-In New Engines

Many of the heavy-duty detergent oils are especially suitable for breaking in new engines. The high film strength offers maximum protection against scuffing of the comparatively rough rubbing surfaces. Where manufacturer's recommendations for break-in are not available, new engines should be broken in gradually up to approximately one-half load using an oil one grade lighter than recommended for normal service. A change to the heavier grade should then be made before full load is placed on the engine. Not only will this method give best protection to engine surfaces during the break-in period, but draining the oil in the middle of the break-in gives the engine a most desirable flushing.

Use in Dirty Engines

When installing heavy-duty detergent oils in engines which have been previously lubricated with an ordinary motor oil, a cleansing action will take place, tending to remove any deposits formed by the previous oil. Overloading of the oil with these contaminants may occur rapidly and more frequent initial oil drains are required to guard against oil system clogging. If the engine is very dirty the oil should be drained after the first few hours of operation. If the engine is fairly clean the first oil drain should be at not more than ½ the normal drain period.

Oil Consumption

Due to the cleansing action of these oils on piston ring, piston skirt and oil line deposits when first installed in an engine in poor mechanical condition, oil pressure may drop slightly and oil consumption may increase. However, with the continued use of these oils the performance of the engine in these respects should gradually improve. Where such improvement does not occur, the engine should be given the needed overhaul indicated by the occurrence of these conditions.

Compatability

Heavy-duty detergent oils meeting Army or Navy specifications are required to be compatible in any proportions. As a general rule, however, mixing of heavy-duty oils, particularly those not meeting the above specifications, should be avoided as much as possible. When planning to change to the use of a different oil, it is preferable to drain the oil system completely and then flush the engine before installing the new product.

Oil Darkens in Service

Filters and engine parts stay cleaner when the heavy-duty detergent oils are used but the oils themselves become darker. This darkening takes place rapidly due to the highly dispersive effect of the oil on any carbon present. Even a small amount of

carbonaceous material is dispersed throughout the oil in a very finely divided state.

Darkens Copper

Many of the heavy-duty detergent oils darken the copper in copper-lead bearings, copper and brass fittings and certain other non-ferrous metals exposed to the oil in engine crankcases. This is advantageous for two reasons:

1. The formation of a black protective plating on the surfaces of copper-lead bearings prevents additional chemical attack. The coating is of almost immeasurable thickness and long endurance tests under all sorts of service conditions have proved the merits under this method of bearing corrosion prevention.

2. By coating copper lines and brass fittings in the engines, the normally high catalytic effect of copper on oil oxidation and sludge formation is greatly reduced.

Rust Prevention

Certain of the heavy-duty detergent oils afford much greater protection to engine surfaces against rusting. These oils, therefore, are especially suitable lubricants for use in engines just prior to shipment or storage or for engines which are run intermittently or may remain idle for an extended length of time.

Effect of Water

When water is added to properly refined straight mineral oils rather rapid separation of the two liquids occur. When added to the heavy-duty detergent oils, however, the water has somewhat less tendency to separate from the oil. This action is probably beneficial when only small quantities of water are involved, since it thereby contributes to the rust preventive qualities of the oil. However, larger quantities of water such as may result from moisture condensation under extended periods of low temperature operation and water leakage may cause an emulsion to form. The presence of excessive water in any engine crankcase is always detrimental. It is especially so with the heavy-duty detergent oils due to this possibility of the formation of an emulsion.

Mechanical Lubricators

Some difficulty may be encountered in the feeding of heavy-duty detergent oils through the usual sight-glass liquids of mechanical lubricators used to supply oil to the cylinders of large stationary Diesel engines. Cloudiness of the liquid and inability to control the size and rate of droplet formation may occur. Pure distilled water has been found more satisfactory than glycerine for use with heavy-duty detergent oils. Ordinarily these lubricators are made of brass or other non-rusting materials, but where iron is used, small amounts of rust preventives can be satisfactorily added to the water where necessary. Freezing of the water can be counteracted by the addition of ethyl alcohol up to 25%, but usually engines equipped with these lubricators are not installed in exposed locations.

Foaming

Originally, some of the heavy-duty detergent oils had a greater tendency to foam than straight mineral oils. This condition has since been generally corrected. It has been found that the tendency to foam is reduced if the oil is kept free from water and also, that the foaming tendency subsides after the oil has been in service.

Air Cleaners

It has been found that under certain conditions some of the heavy-duty detergent oils have a greater tendency to foam in oil-bath air cleaners than straight mineral oils. In most cases, however, these oils can be satisfactorily used in air cleaners of this type provided the oil is maintained at the recommended level in the oil cup.

Oil Filters

Most types of oil filters are satisfactory for use with the heavy-duty detergent oils. Although it has been found that adsorbent or clay type filters such as those containing Fuller's earth remove the additives from some of these oils, many of the more recently marketed oils can be used satisfactorily with this type of filter with only slight additive removal. In some operations certain makes of edge type filters composed of paper discs tend to clog rapidly when used with these oils. On the whole, however, oil filters stay cleaner for longer periods due apparently to the dispersive action of heavy-duty engine oils.

Oil Reclaiming

The additives in heavy-duty detergent oils are consumed in service by resisting oxidation, dispersing contaminants and maintaining engine parts in a clean condition. Therefore when the oil is drained the amount of these additives used up depends on engine operating conditions and maintenance practice. When these drainings are subjected to the drastic treatments of oil reclaiming units involving heating to high temperatures, the remaining additive is used up in combatting the effect of these high temperatures.

Reclaimed oil, therefore, more nearly becomes a

straight mineral oil, the quality of which is dependent on the base stock used in its original manufacture and the efficiency of the reclaiming process. Addition of a commercial additive to a reclaimed oil offers the difficulty that the additive would not be compatible with the oil because the balance of inhibitors in most inhibited oils has been worked out to a fine degree by the oil refiner. In addition there is no assurance without engine testing that the newly compounded oil will be of proper quality.

Centrifuging

Heavy-duty detergent oils can be used in engines equipped with centrifugal oil purifiers. However, this method of oil purification is less effective than other methods due to the highly dispersive characteristics of the oil. The practice of water washing in conjunction with the centrifuge should be discontinued due to the adverse effect that water has on these oils.

Used Oil Analyses

Some of the conventional tests employed in the testing of used samples of straight mineral oils and ordinary motor oils are not applicable to oils of the heavy-duty detergent type.

For example, the test for precipitation number which involves centrifuging the oil at high speed and measuring by volume the amount of foreign material thrown out gives a fictitiously high value due to the excellent dispersive action of these oils. This dispersion prevents the finely dispersed particles from forming a compact sediment as a result of the centrifugal action and a higher value is thereby observed.

In the copper strip corrosion test many of these oils give a dark, tarnished appearance to the copper strip characteristic of the protective coating they give to copper-lead bearings. This appearance defies the detection of corrosive tendencies by the usual visual observation and nullifies the importance of this test.

Neutralization number test as determined by the usual ASTM method gives fictitious results with oils containing certain types of additives which react to the chemicals used in this test.

High ash value reflects the presence of metallo-organic compounds used as detergent additives in the oil and hence do not necessarily indicate only foreign mineral matter contamination.

APPLICATION AND RECOMMENDED USES

Heavy-duty detergent oils were specifically designed and are recommended for all high-speed engines both gasoline and Diesel types. Many medium-speed Diesels equipped with a single lubrication system are using these oils where improved ring lubrication is desired. They are also suitable for the cylinder lubrication of large low-speed engines requiring greater protection against ring sticking or wear.

The successful performance of these oils in high-speed engines has naturally led to many attempts to use them elsewhere. Experience has shown however, that some caution must be exercised when extending the use of oils of this type.

Large Slow-Speed Diesels—Although heavy-duty detergent oils are often used for the lubrication of cylinders in engines of this type, their use in the separately lubricated crankcase is limited by the oil purification equipment employed. The greater dispersion and emulsification properties of these oils tend to prevent satisfactory removal of carbonaceous material and water making it necessary to drain the crankcase oil at regular intervals in order to remove these contaminants. This procedure although particularly desirable for the smaller high-speed engines is far too expensive and time-consuming where crankcase capacities of large engines range as high as 1500 gallons. In such installations a straight mineral oil is used to better advantage in that it can be maintained in a relatively clean condition almost indefinitely. This is accomplished by the purification system's removal of contaminants as rapidly as they are formed.

Where heavy-duty detergent oils are used in these large engines, special precautions must be taken where water-cooled pistons, mechanical lubricators and centrifuges are employed.

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Printed in U. S. A. by
Salley & Collins, Inc.
305 East 45th Street, New York